Incidence of *Bipolaris* and *Fusarium* on Subcrown Internodes of Spring Barley and Wheat Grown in Continuous Conservation Tillage

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ABSTRACT

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Two cultivars each of barley and wheat were planted in three tillage systems (minimum till, chisel plow, and moldboard plow). Subcrown internodes were sampled twice each season (near heading and in the hard-dough to ripening stages) for common root rot and infection by *Bipolaris sorokiniana* and *Fusarium* spp. (*F. acuminatum, F. avenaceum, F. culmorum, F. graminearum*) in the fourth and fifth years of continuous cultivation. No significant interactions occurred between tillage and cultivar for the variables measured. Tillage had no effect on root rot indices (0–100 scale) of barley or wheat sampled at the hard-dough and ripening stages. Indices averaged 57 for barley and 47 for wheat across years. *B. sorokiniana* was isolated more frequently from subcrown internodes of barley (average = 66%) or wheat (average = 58%) in moldboard plow plots than from subcrown internodes of barley (average = 47%) or wheat (average = 40%) in minimum-tillage plots. *Fusarium* spp. were isolated more frequently from subcrown internodes of barley (average = 18%) or wheat (average = 22%) in minimum-tillage plots than from subcrown internodes of barley (average = 7%) or wheat (average = 11%) in moldboard plow plots. Isolation of *F. graminearum* was 10, 5, and 3% from subcrown internodes of barley and 18, 21, and 11% from subcrown internodes of wheat in minimum-tillage, chisel plow, and moldboard plow plots, respectively. Isolation of *F. avenaceum* was 5, 0.6, and 0.9% from subcrown internodes of barley and 6, 0.9, and 0.3% from subcrown internodes of wheat in minimum-tillage, chisel plow, and moldboard plow plots, respectively. Tillage treatment did not affect isolation of *F. acuminatum* or *F. culmorum*.

Additional keywords: Cochliobolus sativus, Gibberella zeae, Hordeum vulgare, Triticum aestivum.

Common root rot frequently occurs on barley (*Hordeum vulgare* L.) and wheat (*Triticum aestivum* L.) in the Great Plains of North America (10,20) and other cereal-growing areas (7,12). Disease symptoms include necrosis of basal stems, crowns, subcrown internodes, and roots. Several fungi are involved, but the most prevalent pathogen is *Bipolaris sorokiniana* (Sacc.) Shoemaker (synonyms *Helminthosporium sativum* Pammel, C. M. King & Bakke and *H. sorokinianum* Sacc. in Sorokin; teleomorph *Cochliobolus sativus* (Ito & Kuribayashi) Drechs. ex Dastur) (10,20). *Fusarium graminearum* Schwabe, *F. culmorum* (Wm. G. Sm.) Sacc. (10,20), and less virulent species (*F. acuminatum* Ellis & Everh.; *F. avenaceum* (Fr.:Fr.) Sacc.; *F. crookwellense* L. W. Burgess, P. E. Nelson & T. A. Toussoun; and *F. poae* (Peck) Wollenweb.) also are associated with common root rot and crown rot (20). These *Fusarium* spp. can occur singly or in combination with *B. sorokiniana*.

Most barley and wheat plants are infected by common root rot fungi before the inflorescence emerges. Aboveground symptoms often are inconspicuous, but lesions on subcrown internodes are typical of the disease (10,20). Severity of common root rot is influenced by the previous crop (8,10,20), so a rotation of at least 2 yr with noncereal crops is recommended. However, suitable alternative crops are not always available, and production of barley or wheat for two or more successive seasons is common.

Conservation tillage practices are being implemented in cereal-growing areas with highly erodable land in compliance to the Conservation Provision of the 1985 Farm Bill. However, reports on the effects of reduced tillage on common root rot are conflicting. An 11-yr study in Canada found no consistent differences in common root rot ratings when wheat was grown under conventional tillage (blade tillage) and minimum tillage (2). However, in northern Texas, populations of *B. sorokiniana* were highest in the top 10 cm of soil, and incidence and severity of common root rot usually were significantly higher in conventional-till plots than in no-till plots (9).

Objectives of this study were to determine the effect of three tillage systems (minimum till, chisel plow, and moldboard plow) on common root rot on barley and wheat during the fourth and fifth seasons of continuous cultivation and to quantify the incidence of subcrown internodes infected by *B. sorokiniana* and pathogenic *Fusarium* spp. (*F. acuminatum, F. avenaceum, F. culmorum, F. crookwellense, F. graminearum,* and *F. poae).* A brief report has been published (22).

MATERIALS AND METHODS

Field preparation. Tillage trials were initiated in 1982 at the Northwest Experiment Station, University of Minnesota, Crookston. The field was treated with glyphosate (1.7 kg a.i./ha). Postemergence herbicides were applied in subsequent seasons and included diclofop plus bromoxynil (0.84 plus 0.28 kg a.i./ha or 1.12 plus 0.21 kg a.i./ha) or bromoxynil (1.05 kg a.i./ha). The spring wheat cultivar Era was planted in a 67- × 280-m field. After harvest, the field was divided into a split-plot arrangement of tillage treatments (minimum till, chisel plow, and moldboard plow) as main plots in a randomized complete block design with four replications. There were 9-m alleys between tillage plots within each replicate and 15-m alleys between replications. Alleys were tilled as needed to control weeds. Plots designated for moldboard plow tillage were tilled with a moldboard plow, tandem disk, and a multiweeder plus spring-tined harrow in the fall of each year from 1982 to 1986. Plots selected for chisel plow tillage were tilled with a chisel plow each fall from 1982 to 1986. Minimum-till plots were not disturbed each fall except when anhydrous ammonia was applied. In the following spring seasons of 1983–1987, all main plots were lightly tilled with a multiweeder to prepare a seedbed. On the basis of soil analysis after harvest each year, plots were fertilized at rates to ensure maximum yield.

Each tillage main plot was split and planted with spring barley and wheat. Half of each plot was planted to barley (cultivars Morex and Robust) and half to wheat (cultivars Era and Wheaton). Each cultivar subplot measured 10 × 23 m. In the first year of the study (1983), both crops were planted after Era wheat. In subsequent years, the same cultivars of barley and wheat were planted in subplots in which they had previously grown. Grain was planted with a drill set at a 15-cm row spacing on 4 and 5 May 1983, 9 May 1984, 2 May 1985, 20 May 1986, and 20 April 1987. Barley and wheat were sown at a rate of 112–134 and 104–146 kg of seed per hectare, respectively.

Soil surface residue. Amount of residue on the soil surface was measured immediately after fall tillage in 1982–1986 and after spring tillage and planting in 1983–1987. Surface residue was measured by the line-intersect method (15) in four randomly selected areas within each subplot. Three-meter-long ropes, marked in 12-cm increments, were placed at right angles to the direction of tillage and planting, and the number of marks that contacted residue was recorded.

Root rot evaluations. In 1986 and 1987, after the fourth and fifth year of continuous tillage, both cultivars of barley and wheat were indexed for root rot. Fifty plants were randomly sampled from each subplot, except from the middle 1.5 m, which was harvested. Barley was sampled when plants were in the late-boot (49 on the Zadoks scale) and ripening (Zadoks 91) stages (23). Wheat was sampled in 1986 when plants were in the heading (Zadoks 59) and hard-dough (Zadoks 87) stages, and in 1987 when plants were in the milk (Zadoks 71) and ripening (Zadoks 91) stages. The crops were sampled at different stages in the two seasons because unfavorable weather precluded sampling at the same stages. Subcrown internodes (1.5–3.5 cm in length) were rated on a 0–3 scale, for which 0 = healthy, 1 = 1–25% of the total area covered by lesions (mild), 2 = 26–50% covered by lesions (moderate), and 3 = >50% covered by lesions (severe) (19). A root rot index was calculated for each subplot (19):

$$\frac{\Sigma\ (\text{Category value} \times \text{number of plants in category}) \times 100}{\text{Total number of plants} \times 3}$$

When wheat and barley subplots were sampled in 1987, some plants lacked subcrown internodes. This was attributed to shallow planting (4,18). An additional 100 plants from each subplot were sampled to determine whether tillage system affected presence of subcrown internodes.

Isolation and identification of common root rot fungi. Subcrown internodes rated in the 1–3 categories were surface-treated in 0.5% NaOCl for 30 s, rinsed twice in sterile distilled water, drained on paper towels, and placed on potato-dextrose agar (Difco Laboratories, Detroit, MI). Dishes were placed 48.5 cm below a combination of three fluorescent 40-W tubes supplemented with two black tubes, F40 BLB series (General Electric, Cleveland, OH), for a 12-h photoperiod for 1–2 wk. Cultures were examined and identified. *Fusarium* cultures that were pink to red (characteristic of species in the sections *Arthrosporiella, Discolor, Gibbosum, Roseum,* and *Sporotrichiella*) were transferred or hyphal-tipped to carnation leaf agar and potato-dextrose agar prepared from fresh potatoes (11). After 10–14 days, *Fusarium* spp. were identified (11). Cultures of *F. graminearum* that formed perithecia of *Gibberella zeae* (Schwein.) Petch on carnation leaf agar were examined for mature ascospores.

Yield. Grain was harvested with a small plot combine through the middle of each plot (1.5 × 7.6 m).

Data analysis. Statistical analyses (analyses of variance and mean separations) were computed with the Statistical Analysis System (SAS Institute Inc., Cary, NC). Data for barley and wheat were analyzed separately by standard procedures for the analysis of a split-plot design; tillage systems were treated as main plots and cultivars as subplots. When percentage data covered a wide range of values, arcsine transformations were performed. When percentage data contained values between 0 and 20, data were transformed by taking the square root of each value plus 0.5. Means were separated with Student-Newman-Keuls' test ($P = 0.05$, unless otherwise indicated).

RESULTS

Soil surface residue. After fall tillage over five seasons, residue covered an average of 84% of the soil surface in minimum-tillage plots, 38% in chisel plow plots, and 11% in moldboard plow plots (Table 1). After spring tillage and planting, the amount of residue on the soil surface was reduced and over five seasons averaged 47% in minimum-tillage plots, 30% in chisel plow plots, and 4% in moldboard plow plots.

Tillage and cultivar effects. Data are presented for only the main effects of tillage and cultivar because there were no significant interactions for any of the variables measured (root rot, incidence of common root rot fungi, or yield).

Root rot evaluations. Neither tillage nor cultivar affected root rot indices or percentage of subcrown internodes with lesions on barley at the two sampling times in either season (Table 2).

Lesions occurred on an average of 66% of subcrown internodes sampled in the late-boot stage and on 89% sampled in the ripening stage (Table 2).

On the first sampling date of wheat in 1986, the root rot index was significantly lower in minimum-tillage plots than in chisel plow and moldboard plow plots (Table 3), but in 1987 the root rot index was significantly lower in the moldboard plow plots than in the chisel plow plots. However, at the last sampling date in both years, type of tillage had no apparent effect on root rot.

TABLE 1. Percentage of soil surface covered by residue in three tillage systems after fall tillage (1982–1986) and after spring tillage and planting (1983–1987)

	Soil surface covered by residue per tillage system (%)[z]					
	Minimum till		Chisel plow		Moldboard plow	
Year	Fall	Spring	Fall	Spring	Fall	Spring
1982–83	91	46	35	30	10	7
1983–84	68	43	35	33	12	5
1984–85	84	65	42	35	17	4
1985–86	89	29	38	24	11	4
1986–87	89	53	39	30	6	2
$\bar{x}$	84	47	38	30	11	4

[z] Each value is based on an average of four locations within both crops of four blocks (32 observations), based on the line-intersect method (15).

No significant differences in root rot occurred between the two wheat cultivars for any of the sampling dates. The percentage of subcrown internodes with lesions followed patterns similar to those of root rot index values (Table 3). Lesions occurred on an average of 84% of subcrown internodes sampled in the hard-dough and ripening stages.

Tillage did not significantly affect percentage of barley (Table 2) or wheat (Table 3) plants with subcrown internodes. Plants in minimum-tillage plots were observed with subcrown internodes somewhat shorter than those collected in chisel plow and moldboard plow plots. In 1987, subcrown internodes occurred on 68% of plants of barley cultivar Robust and on 83% of Morex plants (Table 2). There were no significant differences in percentage of plants with subcrown internodes for the two wheat cultivars (Table 3).

Yield. Yields were not different among barley tillage treatments or cultivars (Table 2). In 1986, wheat yields were significantly different and, in order of sequence from low to high, were from minimum-till, chisel plow, and moldboard plow plots (Table 3). In 1987, wheat yields did not vary significantly among tillage systems. Yields of the wheat cultivar Wheaton were statistically greater than those of Era in both seasons.

Incidence of *B. sorokiniana*. In 1986, after 4 yr of continuous cultivation of barley, *B. sorokiniana* was isolated more frequently from subcrown internodes in moldboard plow plots than from those in chisel plow and minimum-tillage plots at the late-boot

TABLE 2. Effect of tillage system and barley cultivar on root rot index values and percentage of plants with lesions on subcrown internodes (SCI) for two sampling dates per season, percent plants with SCI in 1987, and yield in the fourth (1986) and fifth (1987) seasons of continuous cultivation

	Root rot index[w,x]				Plants with lesions on SCI (%)[x]				Plants with SCI (%)[y]	Yield (kg/ha)	
	1986		1987		1986		1987				
Variable	Late boot	Ripening	Late boot	Ripening	Late boot	Ripening	Late boot	Ripening	1987	1986	1987
Tillage System											
Minimum	27	61	28	46	63	91	66	84	68	4,241	4,876
Chisel plow	21	55	37	60	50	85	75	94	81	4,205	5,099
Moldboard plow	29	68	35	51	69	91	75	89	77	4,379	5,115
P value[z]	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Barley cultivar											
Morex	27	63	35	57	64	92	74	91	83	4,247	4,918
Robust	25	59	32	48	57	86	69	87	68	4,303	5,144
P value[z]	NS	NS	NS	NS	NS	NS	NS	NS	*	NS	NS

[w] Range = 0–100, for which 0 = healthy and 100 = all SCI > 50% covered by lesions.
[x] Mean value for each tillage system is based on 100 plants per replication, and mean value for each cultivar is based on 150 plants per replication.
[y] Mean value for each tillage system is based on 200 plants per replication, and mean value for each cultivar is based on 300 plants per replication.
[z] NS = Not statistically significant; * = statistically significant at $P < 0.05$.

TABLE 3. Effect of tillage system and wheat cultivar on root rot index values and percentage of plants with lesions on subcrown internodes (SCI) for two sampling dates per season, percent plants with SCI in 1987, and yield in the fourth (1986) and fifth (1987) seasons of continuous cultivation[v]

	Root rot index[w,x]				Plants with lesions on SCI (%)[x]				Plants with SCI (%)[y]	Yield (kg/ha)	
	1986		1987		1986		1987				
Variable	Heading	Hard dough	Milk	Ripening	Heading	Hard dough	Milk	Ripening	1987	1986	1987
Tillage system											
Minimum	19 a	34	22 ab	56	46 a	78	57 b	89	71	2,417 a	5,045
Chisel plow	28 b	38	25 b	61	61 b	80	60 b	96	78	2,639 b	4,953
Moldboard plow	33 b	39	19 a	51	73 b	78	44 a	85	91	3,251 c	5,342
P value[z]	*	NS	*	NS	*	NS	*	NS	NS	*	NS
Wheat cultivar											
Era	26	37	21	55	58	78	49	90	81	2,627 a	4,825 a
Wheaton	28	37	23	57	61	80	58	89	79	2,912 b	5,401 b
P value[z]	NS	NS	NS	NS	NS	NS	NS	NS	NS	*	*

[v] Values followed by the same letter are not statistically different by Student-Newman-Keuls' test.
[w] Range = 0–100, for which 0 = healthy and 100 = all SCI > 50% covered by lesions.
[x] Mean value for each tillage system is based on 100 plants per replication, and mean value for each cultivar is based on 150 plants per replication.
[y] Mean value for each tillage system is based on 200 plants per replication, and mean value for each cultivar is based on 300 plants per replication.
[z] * = Statistically significant at $P < 0.05$; NS = not statistically significant.

stage ($P = 0.004$) (Fig. 1A). At the ripening stage, incidence of infection by *B. sorokiniana* was not significantly different among tillage systems ($P = 0.14$). In the following season, when plants were collected in the late-boot stage, there were no significant differences among tillage systems for percent subcrown internodes infected by *B. sorokiniana* ($P = 0.23$) (Fig. 1B). However, when barley reached the ripening stage, *B. sorokiniana* was isolated more commonly, and in equal frequency, from subcrown internodes in the chisel plow and moldboard plow plots than from minimum-tillage plots ($P = 0.03$) (Fig. 1B).

In 1986, when wheat was sampled at heading after 4 yr of continuous cultivation, *B. sorokiniana* was isolated in decreasing order of frequency from moldboard plow, chisel plow, and minimum-tillage plots ($P = 0.003$) (Fig. 1C). When wheat was in the hard-dough stage, *B. sorokiniana* was isolated more frequently from subcrown internodes in moldboard plow plots than from minimum-tillage plots ($P = 0.005$). In the fifth year of continuous cultivation of wheat, tillage did not significantly affect infection of subcrown internodes by *B. sorokiniana* collected at the milk stage ($P = 0.06$) or at the ripening stage ($P = 0.14$) (Fig. 1D).

Isolation of *B. sorokiniana* from the two barley cultivars did not differ at any sampling date, except at the ripening stage in 1987 ($P = 0.02$) (data not shown). The fungus was isolated from 80 and 66% of the internodes of Morex and Robust, respectively. Isolation of *B. sorokiniana* from wheat was not affected by cultivar, except at the ripening stage in the fourth season of cultivation ($P = 0.03$) (data not shown). The fungus was isolated from 61 and 48% of the internodes of Wheaton and Era, respectively.

Incidence of *Fusarium* spp. *F. crookwellense* was not recovered from subcrown internodes. *F. poae* was isolated only five times. Thus, results on infection of internodes by *Fusarium* spp. are based on the combined isolations of *F. acuminatum, F. avenaceum, F. culmorum,* and *F. graminearum.* These species occurred either singly or in combination with each other or, with *B. sorokiniana,* in subcrown internodes with lesions. *Fusarium* spp. were isolated less frequently (Fig. 2) than *B. sorokiniana* (Fig. 1).

Isolation of *Fusarium* spp. from subcrown internodes of barley in the fourth year of continuous cultivation was more frequent in minimum-tillage plots than in moldboard plow plots at the late-boot stage ($P = 0.04$) and the ripening stage ($P = 0.01$) (Fig. 2A). In the fifth year of continuous cultivation, isolation of *Fusarium* spp. from subcrown internodes of barley in the late-boot stage was greater in minimum-tillage and chisel plow plots than in moldboard plow plots ($P = 0.05$) (Fig. 2B). When barley reached the ripening stage, tillage did not affect incidence of

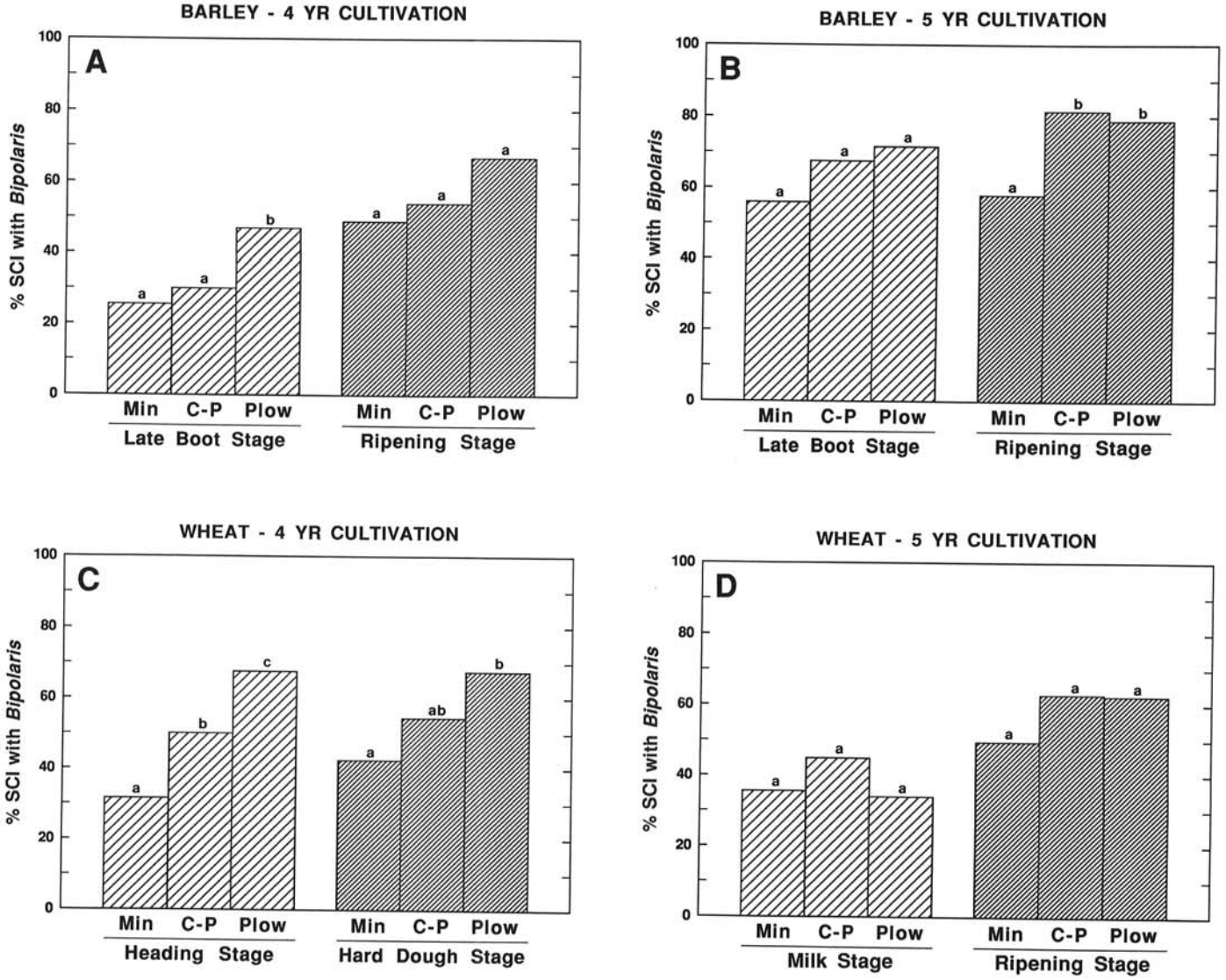

Fig. 1. Percent subcrown internodes (SCI) of barley and wheat infected by *Bipolaris sorokiniana* at two stages of plant growth per season after continuous cultivation of **A,** barley for 4 yr; **B,** barley for 5 yr; **C,** wheat for 4 yr; and **D,** wheat for 5 yr. Three tillage systems were used: minimum till (Min), chisel plow (C-P), and moldboard plow (Plow). Value for each bar is based on isolations from SCI with lesions out of 400 plants that were sampled. For each sampling date, bars with the same letter are not statistically different by Student-Newman-Keuls' test ($P < 0.05$).

Fusarium spp. in subcrown internodes ($P = 0.25$) (Fig. 2B).

At the heading stage in the fourth season of continuous cultivation of wheat, isolation of *Fusarium* spp. from subcrown internodes was low and similar among tillage treatments ($P = 0.11$) (Fig. 2C). At the hard-dough stage, isolation of *Fusarium* spp. from subcrown internodes in minimum-tillage and chisel plow plots was greater than in moldboard plow plots ($P = 0.03$) (Fig. 2C). Plants sampled at the milk stage in the fifth year of continuous wheat yielded more *Fusarium* spp. from minimum-tillage than from moldboard plow plots ($P = 0.06$) (Fig. 2D). At the ripening stage, *Fusarium* spp. were recovered from 39% of subcrown internodes in minimum-tillage plots, 44% in chisel plow plots, and 27% in moldboard plow plots ($P = 0.04$) (Fig. 2D).

In 1986 and 1987, *F. graminearum* was isolated more frequently from internodes of barley at the ripening stage in minimum-tillage plots than from internodes in moldboard plow plots (Table 4).

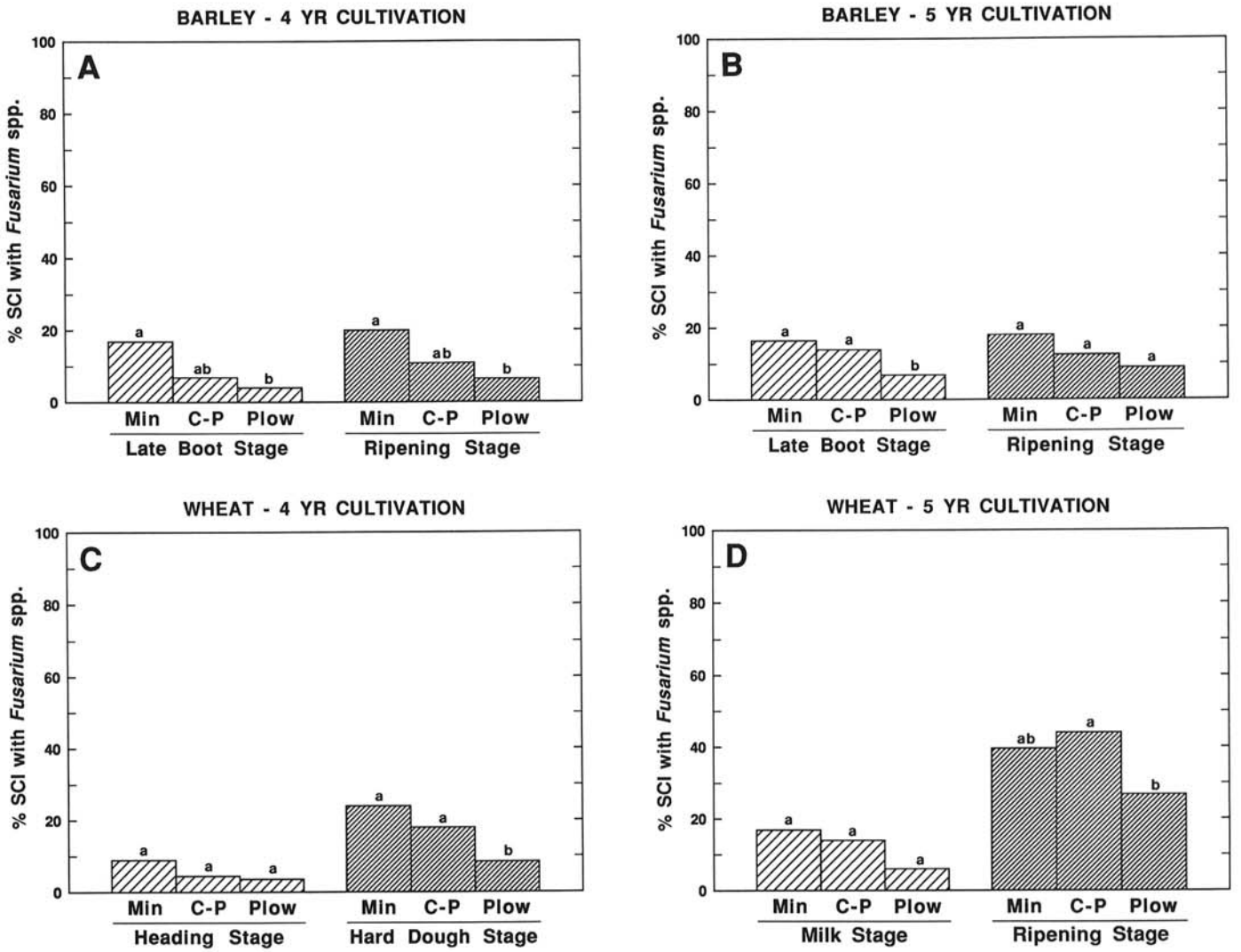

Fig. 2. Percent subcrown internodes (SCI) of barley and wheat infected by *Fusarium* spp. (*F. acuminatum, F. avenaceum, F. culmorum,* and/or *F. graminearum*) at two stages of plant growth per season after continuous cultivation of **A,** barley for 4 yr; **B,** barley for 5 yr; **C,** wheat for 4 yr; and **D,** wheat for 5 yr. Three tillage systems were used: minimum till (Min), chisel plow (C-P), and moldboard plow (Plow). Value for each bar is based on isolations from SCI with lesions out of 400 plants that were sampled. For each sampling date, bars with the same letter are not statistically different by Student-Newman-Keuls' test ($P < 0.05$).

TABLE 4. Effect of tillage system on percent subcrown internodes (SCI) of barley and wheat infected by four *Fusarium* spp. at the hard dough to ripening stages

	SCI infected by *Fusarium* spp. (%)									
	Barley					Wheat				
	Gr[y]					Gr				
Tillage	1986	1987	Av[z]	Ac[z]	Cul[z]	1986	1987	Av	Ac	Cul
Minimum	8 a	12 a	5	3	2	13 a	23 ab	6	8	1
Chisel plow	4 b	6 ab	<1	5	1	9 ab	32 a	<1	8	2
Moldboard plow	3 b	3 b	<1	3	1	4 b	18 b	<1	6	1

[y] Gr = *F. graminearum*. Mean value for each tillage system is based on isolations from SCI with lesions out of 400 plants that were sampled (100 plants per four replicates). For each column, values followed by the same letter are not statistically different by Student-Newman-Keuls' test ($P < 0.05$).

[z] Av, Ac, and Cul = *F. avenaceum*, *F. acuminatum*, and *F. culmorum*, respectively. Mean value for each tillage system is based on isolations from SCI with lesions out of 800 plants that were sampled (100 plants per four replicates in two seasons).

At the last sampling date in 1986, *F. graminearum* was isolated more frequently from internodes of wheat in minimum-tillage plots than from internodes in moldboard plow plots, but in 1987 it was isolated more often in chisel plow plots than in moldboard plow plots (Table 4). Of 667 isolates of *F. graminearum* tested, 97% formed mature perithecia of *G. zeae,* which indicated predominance of the group 2 population (data not shown).

Effect of tillage on each of the other *Fusarium* spp. from subcrown internodes of barley and wheat at the last sampling dates was not analyzed statistically because of the low percentage of isolation. Similar trends occurred in both seasons, so data are averaged for each crop (Table 4). Isolation of *F. avenaceum* was more frequent from minimum-tillage plots of either barley or wheat than from other tillage treatments. *F. acuminatum* and *F. culmorum* were not affected by tillage treatment.

DISCUSSION

After several seasons of continuous cultivation of barley and wheat, incidence of late-season common root rot was not affected by tillage. Yield differences that occurred among tillage treatments for wheat in the fourth season (1986) of continuous cultivation are probably related to foliar diseases (R. D. Wilcoxson and J. V. Wiersma, *unpublished*). Plots sampled in this study were not treated with foliar fungicides because weather conditions often are too dry for leaf spots to affect grain yield in the immediate geographic area. In an 11-yr study in Canada, yield differences between tillage systems were more affected by weed control, seed placement, or soil moisture content than by root rot (2). Soil moisture was not measured in this study, so it is not known whether it varied with tillage treatment.

Rotation of cereals with broadleaf crops is recommended to reduce populations of *B. sorokiniana* (8,10,20), although under conditions favorable for disease, a low concentration of conidia can result in maximum root rot severity (5). Barley and wheat were not sampled until the fourth and fifth season of continuous cultivation, so the effect of continuous cultivation on the population level or on the aggressiveness of *B. sorokiniana* is unknown. Cultures of *B. sorokiniana* isolated from barley and wheat after 5 yr of continuous cultivation were most pathogenic to the host species from which the culture originally was isolated (1). Continuous cultivation of wheat for 90 yr can result in isolates of *B. sorokiniana* that are more aggressive than isolates collected from commercial wheat fields (6).

Soil populations of *B. sorokiniana* are larger under conventional tillage than under reduced tillage systems. Regardless of tillage method, most conidia occur in the top 10 cm of soil (9,12,13). Although soil populations of *B. sorokiniana* were not determined, the fungus was isolated more frequently from subcrown internodes in moldboard plow plots than from those of the other tillage plots on both cultivars of each crop for seven of eight sampling times (significant four out of eight times). Higher populations of *B. sorokiniana* near the soil surface are related to sporulation on culm bases, crown roots, subcrown internodes, and seminal roots (3,7). Cultivation is an additional means of introducing conidia into soil from aboveground plant parts.

Differences in soil surface residue affect soil moisture and temperature, root growth, and nutrient uptake, as well as microbial activity, which alters conditions for root infections (16). Soil that is free of residue holds less moisture and undergoes wider temperature fluctuations than soil with residue cover (16). Cultivation with moldboard plow would enhance dry, warm soil conditions. Activity of *B. sorokiniana* is favored in dry, warm environments. May–July 1987 was a season with above-normal rainfall (27 cm vs. a 90-yr average of 23 cm, Northwest Experiment Station weather records). This factor may explain why significant differences in the recovery of *B. sorokiniana* from subcrown internodes occurred less frequently among tillage systems in 1987 (Fig. 1B and D) than in 1986 (Fig. 1A and C), when the season was somewhat drier than normal and May–July precipitation averaged 17 cm.

Isolation of *B. sorokiniana,* either singly or in combination with *F. acuminatum, F. avenaceum, F. culmorum,* and/or *F. graminearum,* may have occurred through invasion of the same site or by independent infections of subcrown internodes. *F. graminearum* and *B. sorokiniana* competed equally well when coinoculated on barley roots, but when inoculated in sequence, the pathogen that was inoculated first was reisolated more frequently (14). Activity of both fungi is favored in warm soils, although in the field, *B. sorokiniana* is the first fungus to enter roots (20). Conditions that favored *B. sorokiniana* to infect internodes in moldboard plow plots more frequently than in minimum-tillage plots may account for the infrequent isolation of *F. graminearum* in moldboard plow plots. Soil temperature was not measured in tillage plots, so its effect on infection of subcrown internodes by any *Fusarium* spp. is uncertain. However, *F. avenaceum,* a species favored by cool, wet soil conditions (20), tended to be most commonly associated with minimum-tillage plots. *F. culmorum* and *F. acuminatum* invaded internodes already infected by *B. sorokiniana,* but internodes "prepossessed" by these *Fusarium* spp. restricted subsequent infection by *B. sorokiniana* (17). In our study, incidence of *F. culmorum* and *F. acuminatum* was unaffected by tillage system.

Shallow planting reduces the length of subcrown internodes (4,18). In the fifth season of continuous cultivation, there was a tendency for fewer barley and wheat plants with subcrown internodes in minimum-tillage plots than in other tillage plots. Although 1987 was a wetter season than 1986, below-normal precipitation in April (0.7 cm vs. a 90-yr average of 4 cm, Northwest Experiment Station) likely favored shallow planting.

Isolations were made only from subcrown internodes of plants with lesions (in the 1–3 disease categories). More internodes had lesions at the second sampling date for barley and wheat than at the first sampling date in both seasons. In a previous study, common root rot fungi were isolated from nearly 30% of subcrown internodes with no lesions (21). Thus, the percentage of subcrown internodes infected by *B. sorokiniana* and *Fusarium* spp. may be underestimated in this study, particularly for the first sampling period of each season. Sometimes subcrown internodes with lesions yielded no fungi.

Tillage system did not affect disease severity but did affect incidence of infection by common root rot fungi on two cultivars of barley and wheat. These results may be site- or region-specific. Incidence and severity of the disease depends on the pathogens present, cropping history, and climatic and edaphic conditions. Conflicting results from other studies on the effects of tillage on common root rot (2,9) reflect sensitivity of the host-pathogen complex to environmental conditions. Implementation of the 1985 Farm Bill (by 1995) requires that at least 30% of the soil surface of highly erodable land be covered by crop residue after planting. This policy highlights the need for long-term research at multiple locations in cereal-growing areas to fully evaluate tillage effects on fungal populations and on disease incidence and severity.

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